# Development of a Solid-State Inflation Balloon for Aerodynamic Drag Assisted Deorbit of CubeSats

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# Overview

- System Concept
- System Overview
- System Modeling
- Prototype Development
- Evaluation Criteria

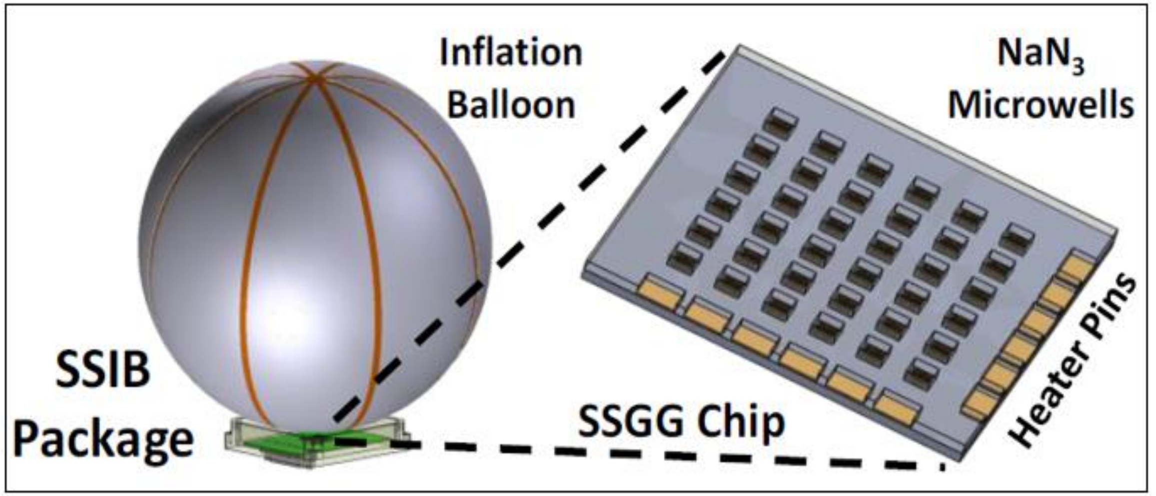
# System Concept

**“Simple, Effective, Low Cost”**

- Deorbit achieved through enhanced aerodynamic drag
  - Drag enhanced with an inflatable spherical balloon
  - No need for attitude control or attitude knowledge
  - No need for a propulsion system
- Balloon inflated with a Solid-State Gas Generator
  - No need for a pressurized gas cylinder
  - Gas is generated ‘on demand’ (unlike subliming solids)
  - Inflation can be maintained over time
  - Gas generator is scalable and has tailorable gas impulse volumes
    - 10s to 1000s of gas impulses per chip
    - 1ng – 10μg
- Low Cost – approx. 500 USD, (excluding labor)

# System Overview

- Solid-State Inflation Balloon (SSIB) Deorbiter
  - Inflation Balloon
  - Package
  - Electronics PCB
  - Solid-State Gas Generator (SSGG)

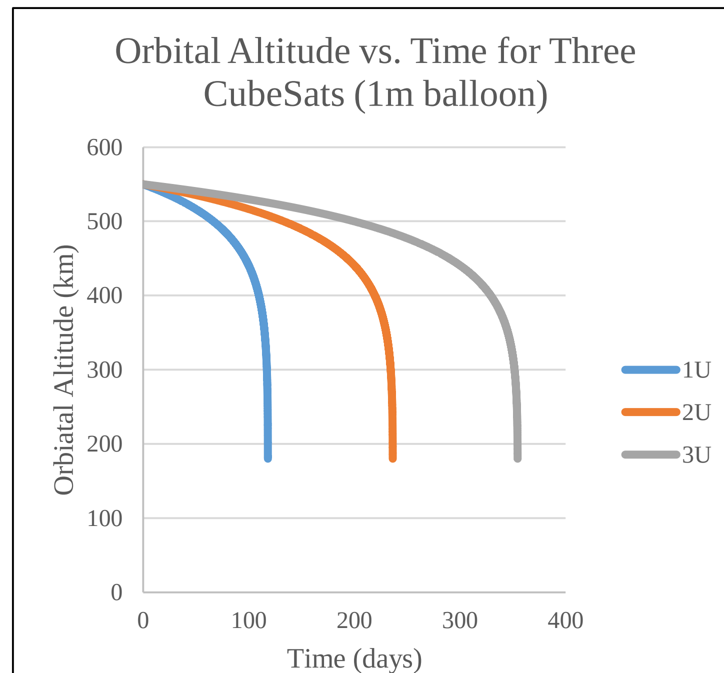



- SSGG is mounted on Electronics PCB
- PCB is contained in the Inflation Balloon
- Balloon is folded and held in the SSIB Package
- SSIB interfaces to CubeSat Bus via a Serial cable
- SSIB is at end-of-mission and maintained with a timer

# Deorbit Modeling

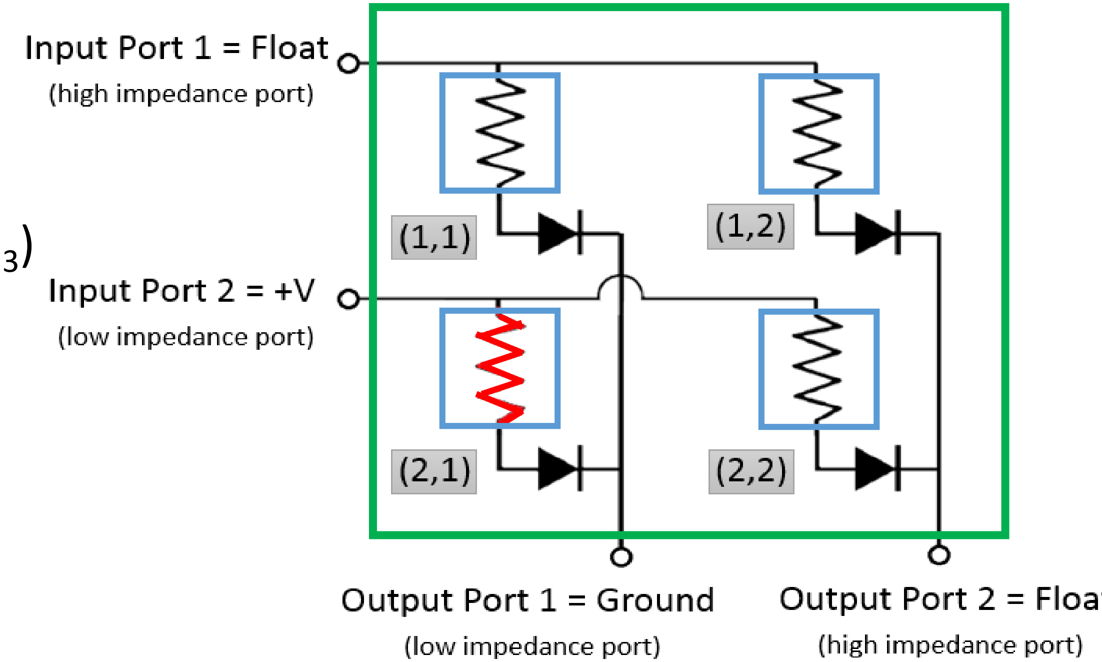
- Used Finite Difference Time Domain approach
  - $\frac{dP}{dt} = -3 * \pi * a * \rho * A * C_d/m$
  - $C_d = 2.2$
  - $dP = -0.1\ s$
  - $m = 1.3kg/U$
  - Atmospheric density based on 1976 Standard Atmospheric Model
- A CubeSat will deorbit in ~9400 days from 550km Orbit (semi-major asix of 9630km)
- Model assumes spherical orbit, independent of inclination

| Deorbit Time in Days for Spacecraft with Different Balloon Diameters | | | | | |
|---|---|---|---|---|---|
| | Balloon Diameter | | | | |
| Spacecraft | 0.5m | 0.75m | 1.0m | 1.25m | 1.5m |
| *1U* | *473* | *210* | *118* | *76* | *53* |
| *2U* | *946* | *420* | *236* | *151* | *105* |
| *3U* | *1419* | *631* | *355* | *227* | *158* |



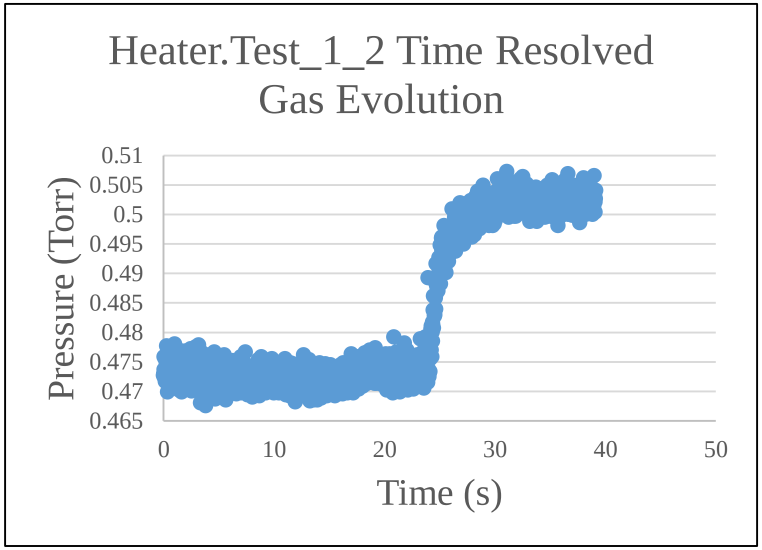
# SSGG Chip Design

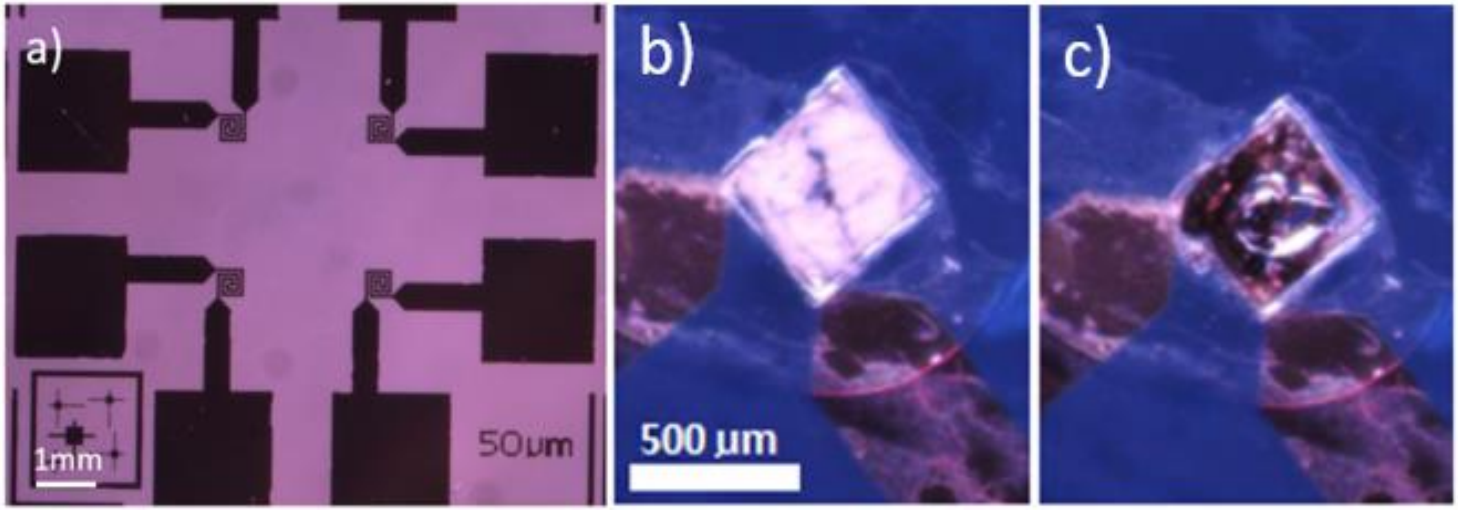
- 3 major elements
- Microwells
  - Microwells are loaded with Sodium Azide ($NaN_3$)
  - 20 nL microwell volume
- Resistive heaters
  - Resistive heaters thermally decompose $NaN_3$ into $N_2$
- Metal-Insulator-Metal diodes
  - Diodes allow for individual addressing of heaters
- Device is built with microfabrication technology



# Heater Design

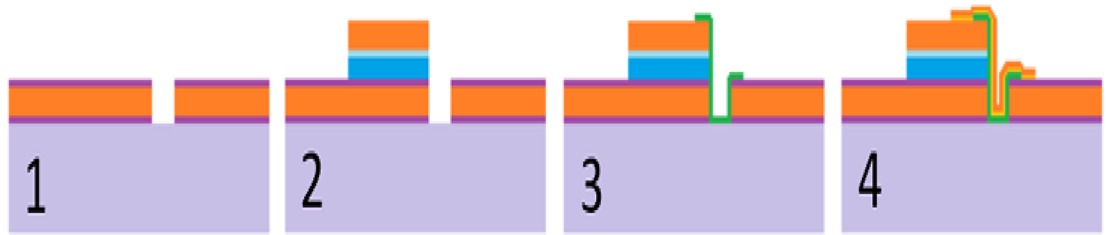
- Explored a wide range of heater materials
  - Ti-Cu-Ti
  - Ti-Cu
  - Ti
  - Ti-Au
  - Ti-Pt
- Heater will be temperature controlled with RTD feedback loop
- Wells are filled with $NaN_3$ surface wetting properties

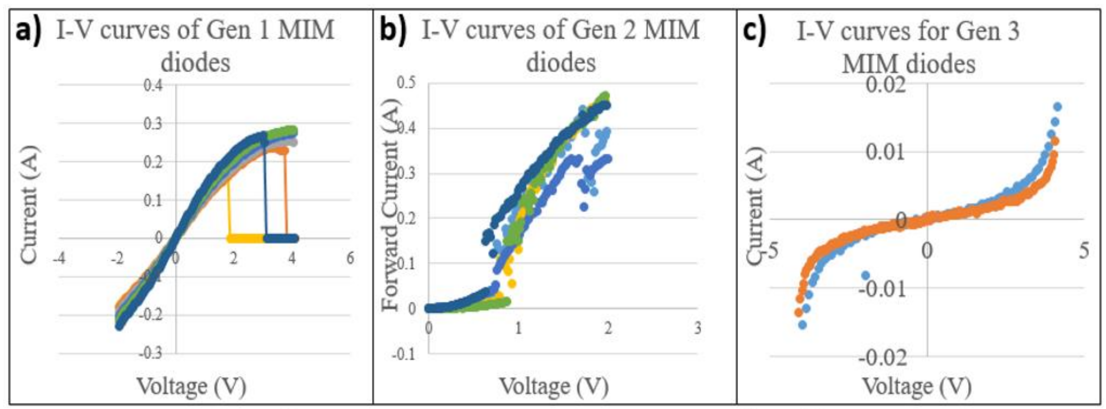


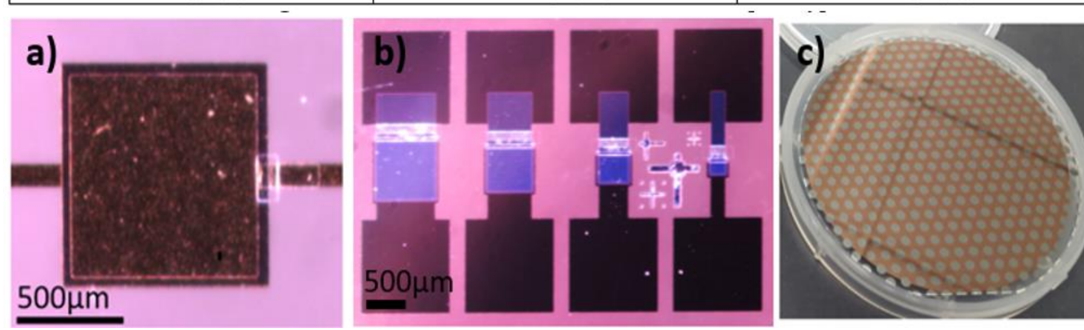



# MIM Diodes

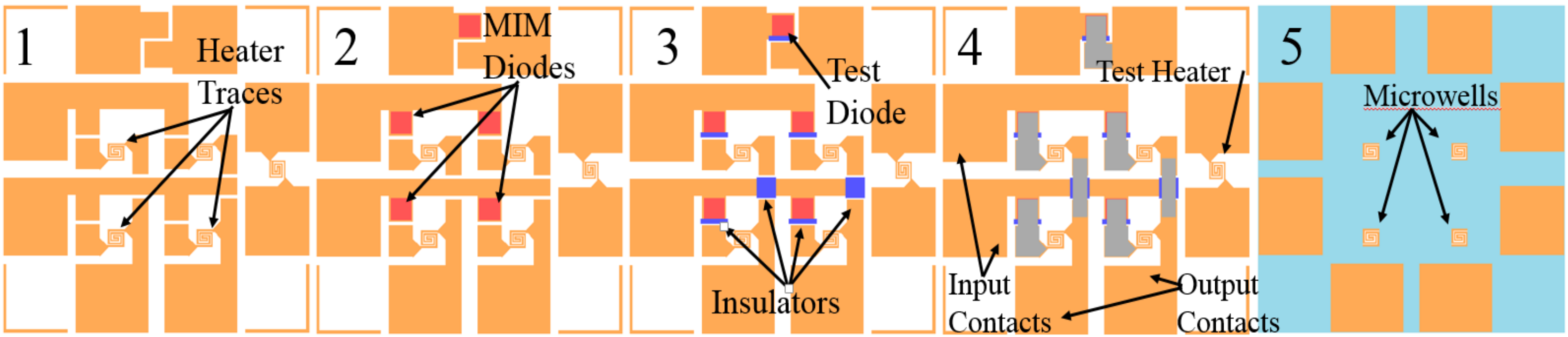
- Quantum Tunneling Diode
- Fabricated with 'Lift-off' process
- Three Generations were prototyped
  - Gen 1 established a general fabrication process
  - Gen 2 refined the fabrication process for integration with SSGG
  - Gen 3 helped clarify desired insulator thickness

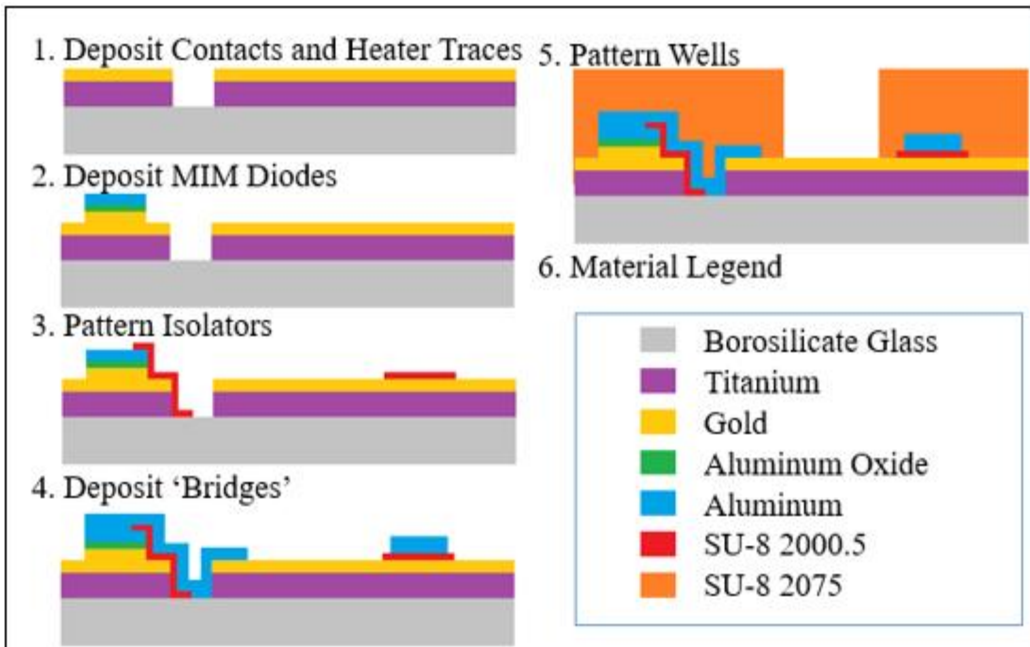


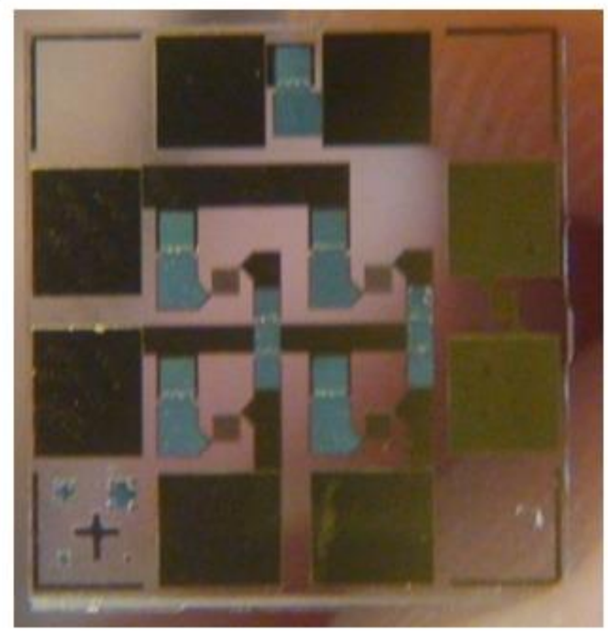



# SSGG Design


1
Heater
Traces
2
MIM
Diodes
3
Test
Diode
Insulators
4
Test Heater
Input
Contacts
Output
Contacts
5
Microwells


1. Deposit Contacts and Heater Traces
2. Deposit MIM Diodes
3. Pattern Isolators
4. Deposit 'Bridges'
5. Pattern Wells
6. Material Legend
Borosilicate Glass
Titanium
Gold
Aluminum Oxide
Aluminum
SU-8 2000.5
SU-8 2075

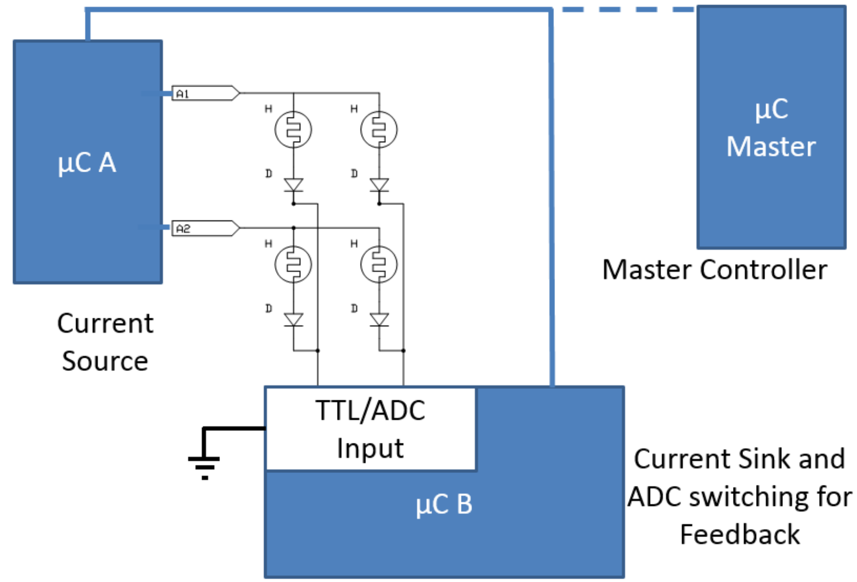


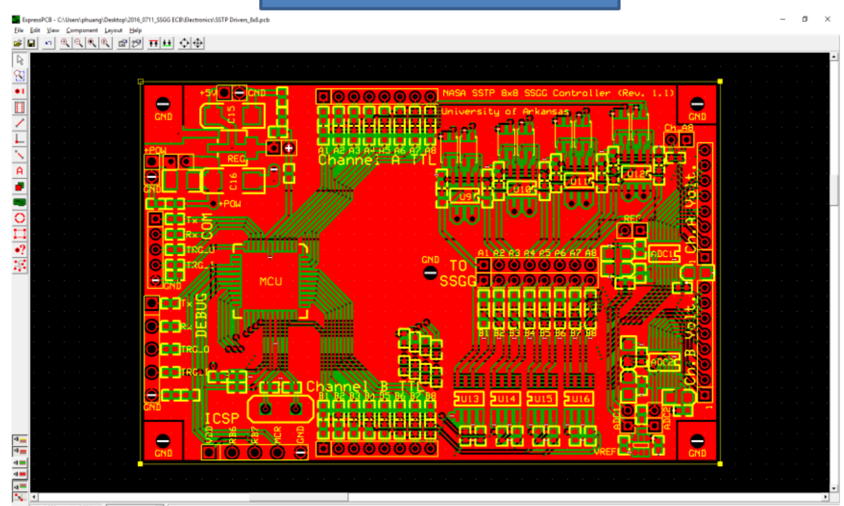
# Balloon Development

- Development in progress
- Investigating various materials
  - Kapton
  - Metallized Polyimide
  - Mylar
  - Teflon
- 0.5m diameter Mylar balloon has been prototyped
- Cut 2D shapes and assemble into 3D structure
- Goal: use heat welding to create spherical balloons from lenticular gores

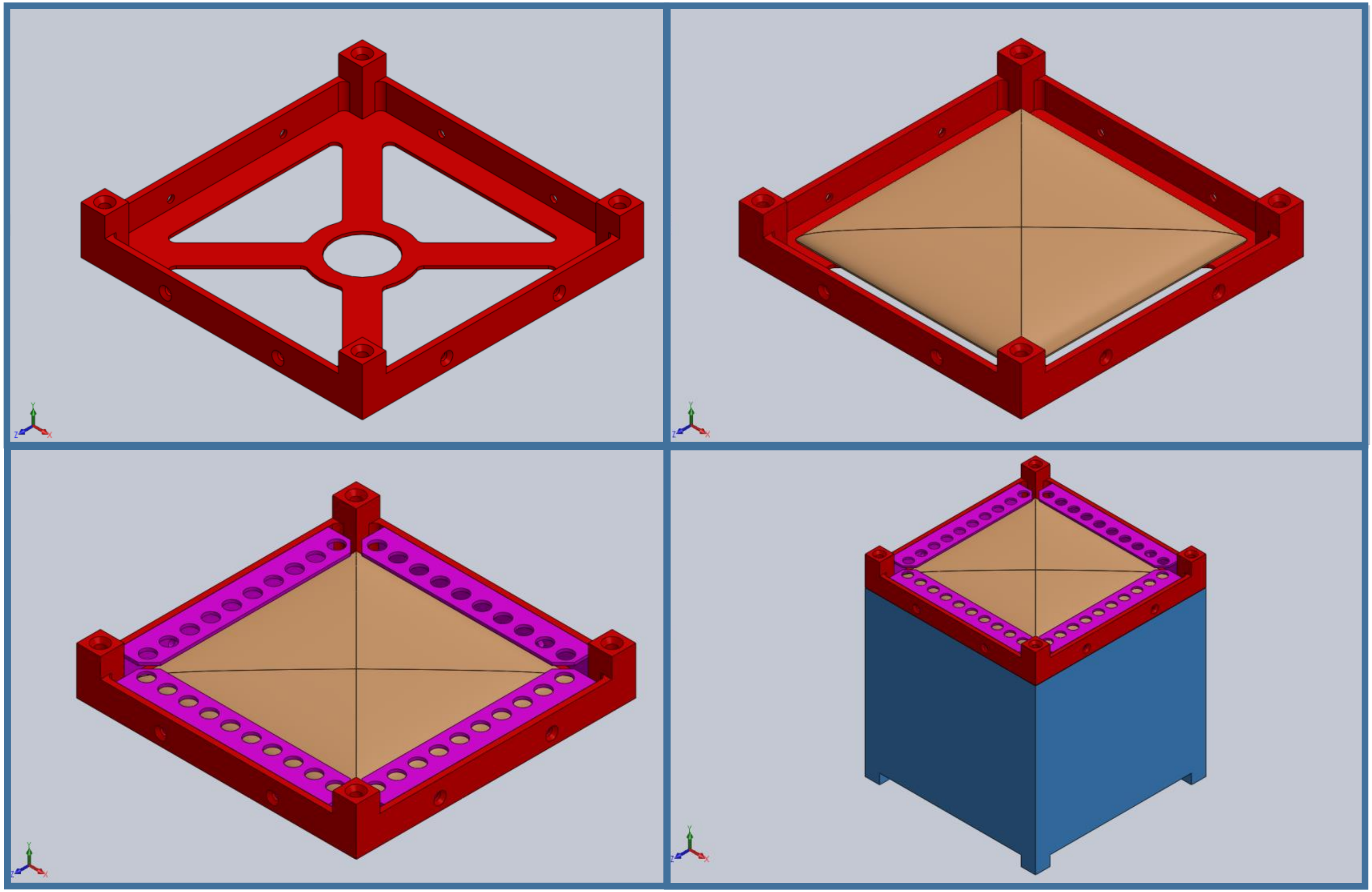
# Electronics Control Board

- Microcontroller based driver electronics
- Composed of one primary µC and two secondary µCs
- µCs are operated in an switched Read/Write mode
    - Primary µC coordinates
    - µC A drives current
    - µC B sinks and measures current for feedback



# SSIB on 1U CubeSat



# Evaluation Criteria

- Effectiveness
  - Natural lifetime is ~9,400 days (25.8 years)
  - Lifetime with SSIB deorbiter → 118, 236, 335 days for 1U, 2U, 3U (1m diameter balloon)
- Launch Envelope (mass and volume)
  - Volume = ~100cc
  - Mass = 50 - 70g
- Cost (excluding labor)
  - 500 USD
- Feasibility – Mechanical and Electrical
  - SSGG, balloons, and ECB have been prototyped
  - SSGG has been demonstrated to work in vacuum conditions
- Impact on Satellite
  - Minimal – low volume, low mass, brief power usage
  - Can be integrated as a ‘bolt on system’

# Evaluation Criteria Ctd.

- Reliability
  - Built in Redundancy in SSGG
  - Inflation can be maintained over time; actively through direct command or passively with a timer
- Safety
  - Toxicity – LD50 = 29mg/kg in Rats – SSGG will hold < 1 mg of $NaN_3$
  - Safely used in car airbags
  - Shock will be tested at 19g levels
- Maintenance
  - Inflation maintenance can achieved with a timer
  - Balloon failure due to micrometeoroid impact will still be able to achieve deorbit within 25 years
- User Friendliness
  - Plug-and-play
- Debris Risk
  - No additional risk, Balloon will deorbit in ~20 days by itself

# Conclusion

- We have designed a ***Low Cost, Effective, Redundant, and Low Impact*** Deorbiter Subsystem
- SSGG prototype development has been completed
- Integrated SSIB subsystem prototype fabrication is underway
- Goal: Reach TRL 5 by Summer 2017

# Acknowledgements

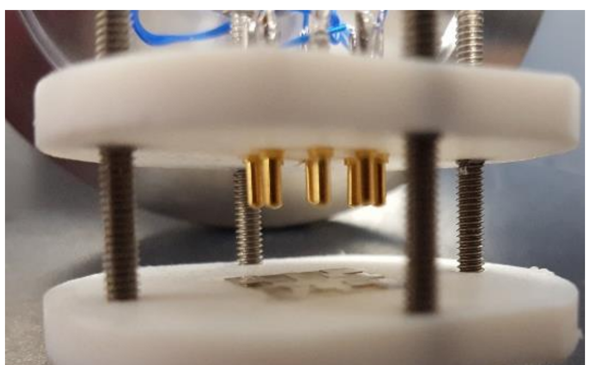

- The author would like to thank the NASA Space Technology Mission Directorate's (STMD) Small-Spacecraft Technology Program (SSTP) funding for this project through the award #NNX15AW38A.
- University of Arkansas Collaborators: Dr Adam Huang, Dr Larry Roe
- NASA Collaborators: David Myers, Alan Cassell, Robin Beck, Kimberly Hines, Bruce Yost, Elwood Agasid

# Questions?

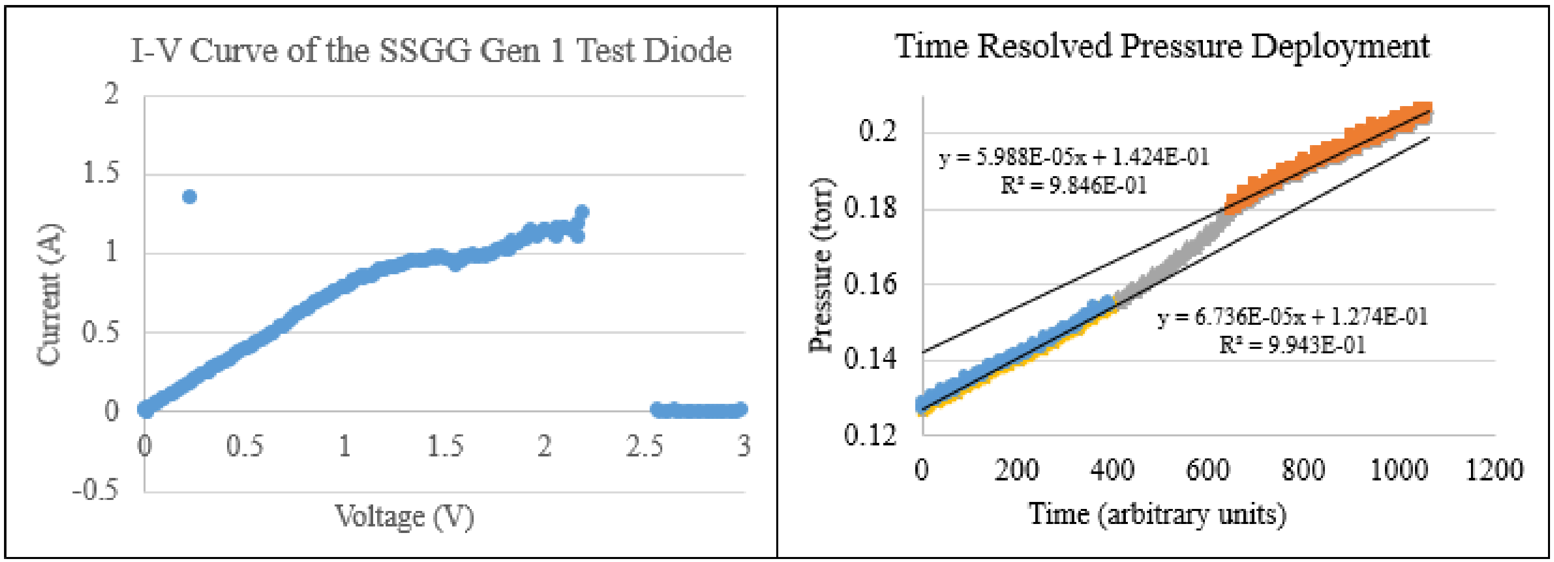
# Volume of Gas at Altitude
## (Ideal Gas Law)

| | Altitude (km) and Pressure (torr) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| | 6.4E-07 | 6.6E-08 | 1.1E-08 | 2.3E-09 | 6.2E-10 | 2.4E-10 | 8.4E-11 | 8.4E-11 | 5.9E-11 |
| Gas Mass (ug) | Spherical Balloon Diameter (m) | | | | | | | | |
| 1 | 1.3 | 2.7 | 4.9 | 8.2 | 12.7 | 17.4 | 24.7 | 24.7 | 27.7 |
| 10 | 2.7 | 5.8 | 10.5 | 17.7 | 27.4 | 37.5 | 53.2 | 53.2 | 59.7 |
| 100 | 5.8 | 12.4 | 22.7 | 38.2 | 59.0 | 80.7 | 114.6 | 114.6 | 128.7 |
| 1000 | 12.6 | 26.8 | 48.8 | 82.3 | 127.1 | 173.9 | 246.9 | 246.9 | 277.2 |

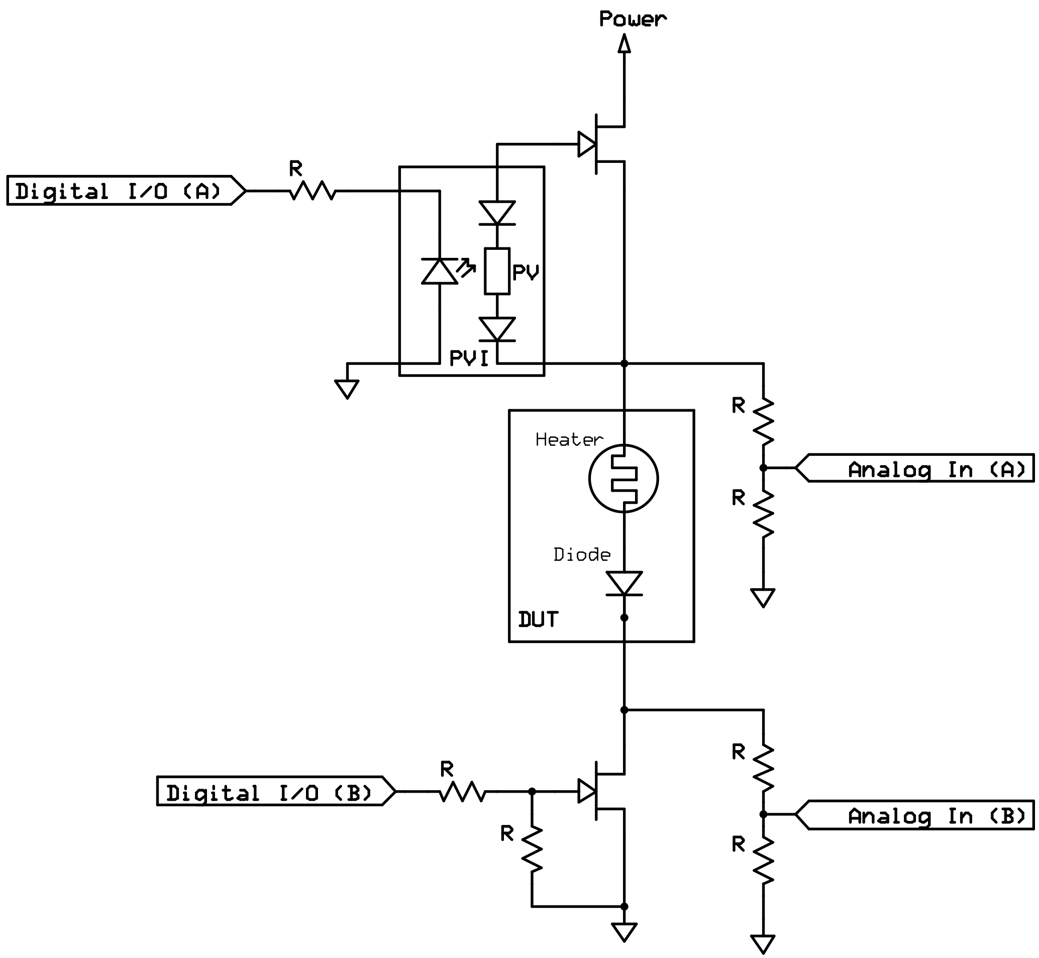
# Gas Volume Measurement



# SSGG Performance



# ECB Ctd.


Power
Digital I/O (A)
R
PV
PVI
R
Heater
Analog In (A)
R
Diode
DUT
R
R
Digital I/O (B)
Analog In (B)
R
R

# Blank